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Sustainable energy crop production

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Biofuels currently supply a small portion of the world's energy needs but this is increasing due to mandates intended to reduce use of fossil fuels and the associated environmental impacts. However, the potentials of plant based feedstocks to substitute for fossil fuels and mitigate environmental impacts are uncertain. Much of the uncertainty is related to the quantification of nitrous oxide (N_2O) emissions from feedstock production and the extent to which use of grain and biomass for biofuel feedstocks leads to land use conversion for compensatory cropping (indirect land use change). Current consensus is that sugar cane, perennial cellulosic crops, and waste biomass provide clear benefits while corn ethanol and oil seed crops may provide benefits if indirect land use change is assumed to be negligible and if recommended crop management practices, such as use of enhanced efficiency fertilizers and minimal tillage, are employed. Future research should better quantify N_2O emissions from different feedstocks grown in different regions, the ability of best management practices to mitigate these emissions, and the potential for marginal lands and increased crop yields to supply biomass.

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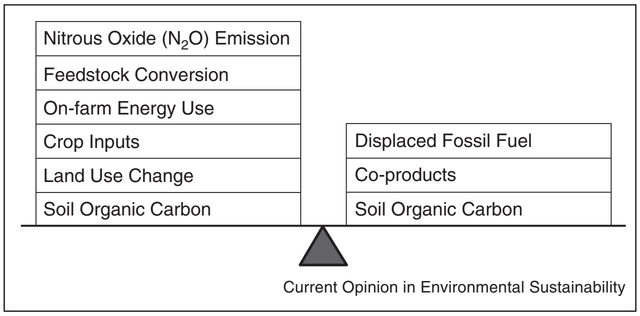
Introduction

Energy crops currently supply approximately 1.5% of electrical power, 3% of heat generation, and close to 3% of liquid transport fuels at the global scale. These portions have increased in recent years and are expected to increase in the future. For example, the International Energy Agency has a goal for biofuels to meet more than a quarter of world demand for transportation fuels by 2050 and at least 35 countries have mandates for blending biofuels. These mandates are intended to support domestic energy security, reduce reliance on imported fossil fuels, and mitigate the environmental impacts, particularly greenhouse gas (GHG) emissions, from fossil fuel combustion. However, the potential of plant based feedstocks to substitute for fossil fuels and the environmental impacts of bio compared to fossil fuels are uncertain. Estimates of the portion of global energy needs that could be supplied by biofuels range from less than 5% to greater than 20% [1]. Similarly, estimates of net GHG emissions of biofuel production systems compared to an equivalent amount of energy from fossil fuel range vary substantially, for example, life cycle assessments of net GHG emissions for corn ethanol compared to fossil fuel in the US range from substantial reductions (86%) to large increases (93%) [2]. Biofuel feedstock type and management, end use of feedstock and conversion efficiencies, previous land use, method used to estimate GHG emissions from feedstock production, and the extent to which co-products and indirect land use change (iLUC) are accounted, impact the GHG balance (Figure 1) of biofuel production systems [1,3•,4]. In particular, GHG emissions from feedstock production and iLUC are difficult to quantify and some researchers claim that many studies showing a GHG benefit of biofuels do so because they underestimate these emissions [5••]. Despite the uncertainty, most agree that feedstock production and N_2O emissions associated with nitrogen (N) inputs to soil are responsible for a large portion of life cycle GHG emissions [1,4]. In this review, we focus on soil GHG emissions (particularly N_2O) from bioenergy productions systems in Brazil, the EU, and the US because Brazil and the US lead the world in ethanol production while the EU is the world's largest biodiesel producer.

Corn ethanol and perennial feedstock systems in the US

Approximately 40% of the US corn harvest and one fourth of the soybean harvest are used to produce ~76 billion litres of ethanol and ~4 billion litres of biodiesel, respectively. Currently, these biofuels supply ~7% of petrol and

Figure 1



Greenhouse Gas (GHG) balance for bioenergy production systems. Soil nitrous oxide (N_2O emissions) and land use change are important, but uncertain, components that often determine if a particular system is a net GHG source or sink. Soil organic carbon appears on both the left (sources) and right (sinks) because, depending on previous land use and current management, soils used for feedstock production can lose or sequester carbon.

~2% of diesel fuel used in the US, and these portions are projected to increase because the Renewable Fuels Standard mandates 117 billion litres of ethanol and 19 billion litres of biodiesel by 2022; furthermore ~75 billion litres of this goal is expected to be from second generation biofuels [U.S. Energy Information Administration; URL: http://www.eia.gov/]. Demand for corn has incentivized conversion of Conservation Reserve Program (i.e. set aside) land in the US to annual cropping. This direct land use change (LUC) accompanied with conventional tillage typically results in soil carbon (C) losses and N_2O emissions that negate GHG benefits of fossil fuel displacement. However, if no till cultivation is practiced then soil C can be maintained [6]. Similarly, N_2O emissions from corn cropping can be minimized by using enhanced efficiency fertilizers [7]. Recent analyses suggest that corn ethanol cropping in the US using improved management practices can provide GHG benefits if iLUC change is not counted [8]. Compared to petrol (94 g CO_2 equiv. MJ^{-1}) estimates of the carbon intensity of corn ethanol range from 25 to 56 g CO_2 equiv. MJ^{-1} if iLUC is not counted to 45–100 or more if iLUC is counted [3,5,8,9]. Some argue [5••] that bioenergy feedstock use of any food or feed crop results in iLUC but there is evidence that iLUC emissions have been exaggerated because increases in cropping intensity, yields, and livestock feed co-products were ignored [10,11••]. Although US corn yields have increased by 13% on average from 2008–2013 compared to 2002–2007, exports have decreased by 20%, suggesting that iLUC should not be ignored. It is also interesting that corn yields in 2012 decreased by 13.5% due to drought, but exports decreased by 55%, suggesting that corn exports are much more elastic than domestic consumption. In contrast to annual crops, most agree that perennial crop feedstocks for second generation biofuels provide clear GHG reductions and could provide large amounts of fuel [12,5••]. For example, eastern forests in the US could supply 60 billion litres by intensively managing abandoned agricultural lands and partial harvest of current forests [13]. Successional biomass on marginal lands in the central US could provide 21 billion litres [14]. Perennial herbaceous vegetation and woody material typically have low N_2O emissions because N inputs are low [15,16]. Woody biomass used for heat and electricity generation also appear to provide clear GHG benefits, although abatement costs are prohibitive for electricity, but favourable for thermal applications [17•]. Perennials have low GHG intensity (<35 g CO_2 equiv. MJ^{-1}) because little N fertilizer is needed to support high production so N_2O emissions are small and iLUC is considered negligible if perennial grasses and trees are grown on marginally lands not used for grain cropping and waste products from existing tree plantations are exploited. For example, wood pellets from logging residues in the southeast US used to replace fossil fuels for electricity generation in the UK have life cycle GHG saving of 50% or more even after accounting for trans-Atlantic transport emissions, partly because ocean freight transport is highly carbon and energy efficient [18].

Biofuel feedstock systems in Europe

The EU fuel quality directive (Directive 2003/30/EC) mandated a reduction in the greenhouse gas intensity in fuel supplied for transportation in the EU. This was to be achieved by the replacement of 5.75% of fossil fuel by biofuels (both petrol and diesel) by 2010, and to raise this target to 10% by 2020. However research using Life Cycle Analysis (LCA) indicated that when all inputs and land use change emissions were considered, some supply chains of biofuel could result in emissions that exceeded the fossil fuels they replaced. This led to a new EU directive in December 2010 which mandated that biofuels should be subject to a certification process that ensured that their use resulted in a 35% reduction in greenhouse gas emissions rising to 50% by 2017, and 60% for biofuels from new production facilities by 2018. Bioethanol and biodiesel accounted for 3.8% of transport fuel in 2011 [EUROSTAT; URL: http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsdcc340]. Ethanol used in Europe is mainly imported from Brazil with some minor production of ethanol from sugar beet and wheat feed-stocks (in the UK). Europe produced 8.6 Mt of biodiesel in 2011 of which, 2.9 Mt was in Germany, and 1.56 Mt in France [EBB (European Biodiesel Board); URL: http://www.ebb-eu.org/stats.php]. To produce biodiesel Europe imports 1.44 Mt of palm oil, 0.58 Mt of soya oil and 0.6 Mt of rape oil. European grown rape seed oil (8.87 Mt) and soya (2.27 Mt) are pressed to produce oil for biodiesel production [FEDIOL (EU Oil and Proteinmeal Industry); URL: http://www.fediol.eu/web/statistics%202012/1011306087/list1187970195/f1.html]. This represents 32% of Europe vegetable oil production.